EFFECT OF RICE HUSK SILICA REINFORCEMENT ON
RECYCLED AA7075 ALUMINUM CHIP MATRIX COMPOSITE

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In the Name of Allah, the Most Beneficent and the Most Merciful

This thesis is dedicated to:

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Abah, Mohd Joharudin Saleh and Mak, Mariam Pondo
Whom I owe all my achievements;

My backbone;
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ABSTRACT

Nowadays, solid waste problem has becomes one of the most popular issues. Due to these problems, recycling becomes more competitive to prevent the shortage of significant aluminum resources while reducing the cost of operating. This research was carried out based on the recycling of aluminum alloy AA7075 reinforced silica by rice husk (waste natural fibers) as metal matrix composite. This study approaches the solid state technique to investigate the effect of rice husk silica as a reinforcement agent in metal matrix composites as it has remarkably lower operation cost and energies compared to conventional recycling by casting. Recycled aluminum chip AA7075 with addition of composition (2.5,5,7.5,10 and 12.5)wt%, of untreated and treated rice husk silica using hydrochloric acid to fasten burning process at different temperature (as-received, 700 and 1000)°C, were prepared by using cold compaction method. The setting of load compaction is 9 tons for 20 minutes and then sintered at temperature of 552°C. The properties of metal matrix composites consisting of physical tests (density, porosity and water absorption), mechanical properties (hardness and compression test) and morphology analysis (optical microstructure and scanning electron microscopy) were investigated. For physical properties, the results show that when the density of metal matrix composite is low, the percentage of porosity and water absorption increases. For mechanical properties, the hardness of metal matrix composite were increased up to 10 wt% of rice husk silica which was 65.93 Hv for untreated, and 69.52 Hv for treated rice husk compared to aluminum chip sample with 53.49 Hv. For the compressive strength, the composition of rice husk silica at 5 wt% gave high strength with 333.63 MPa for untreated, and 322.52 MPa for treated rice husk silica compared to aluminum chip sample with 290.47 MPa.

ABSTRAK

Pada masa ini, masalah sisa pepejal telah menjadi antara isu yang sangat popular. Disebabkan masalah ini, kitar semula bahan telah menjadi persaingan untuk menghalang kekurangan sumber aluminum disamping mengurangkan kos operassi. Kajian ini dijalankan berdasarkan bahan kitar semula aloi aluminum AA7075 yang diperkuat dengan silika dari sekam padi (sisa serat semulajadi) sebagai komposit matriks logam. Kajian ini mendekati teknik keadaan pepejal untuk mengkaji kesan silika sekam padi sebagai ejen tetulang dalam komposit matriks logam dimana ia dapat mengurangkan kos operasi dan tenaga berbanding kitar semula konvensional menggunakan kaedah tuangan. Aluminum AA7075 yang dikitar semula dengan penambahan komposisi (2.5,5,7.5,10 dan 12.5)wt%, dari sekam padi tidak dirawat dan dirawat menggunakan asid hidroklorik untuk mempercepatkan proses pembakaran pada suhu berbeza (bahan yang diterima,700 dan 1000)°C, telah disediakan dengan menggunakan kaedah pemadatan sejuk. Penentuan beban pemadatan adalah 9 tan selama 20 minit dan kemudian di sinter pada suhu 552°C. Ciri-ciri komposit matriks logam terdiri daripada ujian fizikal (ketumpatan, keliangan dan penyerapan air), sifat mekanik (ujian kekerasan dan mampatan) dan analisis morfologi (mikrostruktur optik dan mikroskopi pengimbasan elektron) telah disiasat. Bagi sifat fizikal, keputusan menunjukkan apabila ketumpatan komposit matriks logam mempunyai ketumpatan yang rendah, peratusan keliangan dan penyerapan air meningkat. Bagi sifat mekanik, kekerasan komposit matriks logam meningkat sehingga 10 wt% iaitu 65.93 Hv untuk sekam padi tidak dirawat dan 69.52 Hv untuk sekam padi dirawat berbanding sampel cip aluminum dengan 53.49 Hv. Untuk kekuatan mampatan, komposisi pada 5 wt% memberi kekuatan tinggi dengan 333.63 MPa untuk sekam padi tidak dirawat dan 322.52 MPa untuk sekam padi yang dirawat berbanding sampel cip aluminum dengan 290.47 MPa.

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LIST OF SYMBOLS AND ABBREVIATIONS

ACS	-	American Constitution Society
AMC	-	Aluminum matrix composite
Al	-	Aluminum
Al_2O_3	-	Aluminum oxide
ASTM	-	American Society for Testing and Material
$C_{38}H_{76}N_2O_2$	-	Licowax C Micro powder
CH_3COCH_3	-	Acetone solution
Cr	-	Chromium
CTRHS	-	Treated rice husk silica at 1000°C
Cu	-	Copper
CURHS	-	Untreated rice husk silica at 1000°C
H_2SO_3	-	Sulfurous acid
HB	-	Unit for Brinell hardness test
HCL	-	Hydrochloric acid
HNO_3	-	Nitric acid
HV	-	Unit for Vickers hardness test
IUPAC	-	International Union of Pure and Applied Chemistry
Mg	-	Magnesium
MMC	-	Metal matrix composite
NaOH	-	Sodium hydroxide
NH_4OH	-	Ammonium hydroxide
OM	-	Optical Microscope
RH	-	Rice husk

RHA	-	Rice husk ash
RHS	-	As-received rice husk silica
SEM	-	Scanning Electron Microscope
Si	-	Silicon
SiC	-	Silicon carbide
SiO_2	-	Silicon dioxide
Ti	-	Titanium
Tm	-	Melting temperature
TRHS	-	Treated rice husk silica at 700°C
URHS	-	Untreated rice husk silica at 700°C
UTM	-	Universal testing machine
XRD	-	X-ray Diffraction
XRF	-	X-ray Fluorescence
Zn	-	Zinc

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LIST OF PUBLICATIONS

Journals:

(i) Mohd Joharudin, N.F., Abdul Latif, N., Mustapa, M.S., Mansor, M.N., Siswanto, W.A., Murugesan, J. & Yusof, F. (2019). Effect of Amorphous Silica by Rice Husk Ash on Physical Properties and Microstructures of Recycled Aluminium Chip AA7075. *Materials Science And Technology Engineering*, 3, 283, ISSN:09335137 (Published)

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(iii) Mohd Joharudin, N.F., Abdul Latif, N., Mustapa, M.S., Badarulzaman, N.A. & Mahmod, M.F. Effect of Burning Temperature on Rice Husk Silica as Reinforcement of Recycled Aluminium Chip AA7075. (To be publish)

Proceedings:

(i) Mohd Joharudin, N.F., Abdul Latif, N., Mustapa, M.S., Badarulzaman, N.A. & Mahmod, M.F. Physical Properties and Hardness of Treated Amorphous Silica as Reinforcement of AA7075 Recycled Aluminium Chip. (To be publish)

CHAPTER 1

INTRODUCTION

1.1 Background study

Research on current processing methods to produce and improve the material properties is now becoming more attractive among researchers to fulfill the product demand from industries. Aluminum is one of the unique metal alloys that has excellent corrosion resistance with low density and good strength where it is the world's largest material and the third most prevalent component, representing 8% of the Earth's crust (Aalco metals Ltd., 2018). Flexibility in aluminum allows it to be the most commonly used metal after steel. Pure metal has high resistance to corrosion, and requires less support than most other metals. In general, commercial metals and alloys are more sensitive to corrosion where alloys have high strength and lightweight, containing certain amounts of heavy metals such as nickel, zinc or copper, and have increased the need for surface protection of the material (Hu, Nie, and Ma, 2014). The presence of heavy metal additions significantly affect the susceptibility of the alloy to corrosion, and recently, elevated mechanical strength and corrosion resistance have been mainly inconsistent. Therefore, it is very important to develop adequately safe finishing for these metals. The characteristics of various aluminum alloys have led to the use of aluminum in industrial application as diverse as food preparation, transport, energy generation, architecture, electrical transmission and packaging. According to Canakci and Varol (2014), aluminum and its alloys have significant technological importance in aircraft, defense and automotive industries because of their low weight and elevated specific strength. This can be supported by Joshi, Prakash, and Dabhade (2015) who state that aluminum alloys are quite known in the automotive and aerospace industries due to their light weight to strength ratio and excellent corrosion resistance. Furthermore, in an observation-based on study by Sorrel (2015) found that energy conservation is one of the major challenges of reducing the use of the main natural resources, another method needed to develop and enhance the lightweight materials. The alternative of combining different materials system (metal–ceramic–non-metal) offers opportunity for unlimited variation.

Metal matrix composite (MMC) has been applied in daily life for quite some time in many areas. According to Kainer (2006), these novel materials offer great opportunities for advanced material and development. Depending on the application, the characteristics of metal matrix can be customized to the material. Metal matrix composites meet all the desired conceptions of designer. Although the increasing activity of development contributed to system solutions using composite materials with metal matrix, the use of especially innovative systems, particularly in the area of light metals, has not been realized (Nturanabo *et al*., 2019). This is due to the lack of system stabilization, reliability and inadequate effectiveness correlated with manufacturing and handling problems. Application industries, such as traffic engineering, are very cost-oriented and the industry is not willing to pay extra expenses for the use of such materials. Metal matrix composites only begin the evolution of modern materials for all of these purposes. Aluminum matrix composite (AMC) possesses improved physical and mechanical properties such as superior strength to weight ratio, high strength, high modulus, good ductility, excellent wear resistance, high temperature creep resistance, low thermal expansion coefficient, excellent corrosion resistance and better fatigue strength (Macke *et al.*, 2012). They are commonly used in high performance applications such as industrial, automotive, aerospace, military and electricity industries (Mavhungu *et al.*, 2017; Macke *et al.*, 2012). According to a previous study, aluminum matrix composite is suitable as a potential material for wear resistant applications (Dasgupta, 2012; Surappa, 2003; ASM International, 1989). Various types of ceramic materials, for instance, SiC, Al_2O_3, B_4C and MgO, are widely used to strengthen aluminum alloy matrix. Superior properties of these materials such as refractoriness, high compressive strength, high hardness and wear resistance make them suitable for use as reinforcement in the composites matrix (Mavhungu *et al.*, 2017; Lancaster *et al.*, 2013).

Direct conversion method of aluminum chip recycling has recently been implemented without the melting process to avoid the disadvantages of existing method. So, to improve the contribution of aluminum to the industry, excellent recycling processes need to be developed. Recycling waste material currently has been selected because of the cost of material processing that is much higher than recycled materials produced by conventional method. In placing more emphasis, Ghassemieh (2011) claims that due to the expanding interest in aluminum metal, waste issue is one of the most popular issues that has gotten broad public extension regardless of the increasing usage of aluminum used today originating from recycled automotive components. During the manufacturing process in industries, a large amount of aluminum machined chips is generated after the machining process in various types and sizes of chips due to increased demand from its application. The public concern about global warming has resulted in the manufacturing of secondary aluminum to replace the present use of primary aluminum. According to Sajwani and Nielsen (2017), the main benefits of aluminum recycling are lower manufacturing costs, not affecting the environment, and saving primary aluminum energy, and thus fulfilling the target of global industrial societies. In recent decades, the production of low-cost metal matrix composites reinforced with environmentally friendly materials has been one of the main technology developments. Aluminum alloys reinforced with ceramic particles exhibit superior mechanical properties to non-reinforced aluminum alloys and are therefore a candidate for engineering applications (Saravanan, 2013).

Most of the research work has now been done to develop composites using various recycled wastes, especially in the development of composites using the most environmentally friendly agro-wastes as reinforcement fillers. Rice husk ash (RHA) is a waste of agriculture by abundant product. According to Khan *et al.* (2014), the rice milling sector produces a large amount of rice husk during paddy milling from agricultural fields. Paddy milling process generates about 78 percent of the weight representing rice, bran and broken rice and 22 percent of the weight representing husk. Koteswara Rao (2012) agrees that during the incineration process, an amount of 25 percent of husk weight is converted into ash, known as rice husk ash, and the remaining major 75 percent is organic volatile matter. This statement can also be supported by Rozainee *et al.* (2008), as the percentage of ash in rice husk is about 10-25 times greater than other biomass fuels, and it has a silica content of 85-87 percent, which indicates an elevated amount of porosity, elevated internal surface area and less weight. Natural silica (SiO_2) can be obtained from various extractions of natural resources. Rice husk is one of the natural resources that produce silica. In recent studies, Tiwari and Pradhan (2017) reaffirm that rice husk as well as its ash can be used as a potential reinforcing agent as an outstanding source of silica that can substitute other conventional sources of silica. Rice husk acts as a catalyst in the preparation of advance material since it can reduce cost of material. The main content of rice husk ash is silica as a major element, where rice husk and rice husk ash are often used as reinforcing agents to enhance the mechanical properties of alloys.

The effect of rice husk silica on aluminum-based alloy discovers that rice husk ash is simply mixed with aluminum alloy. The uses of silica from rice husk ash as a reinforcing agent in an aluminum alloy is considered in this research.

1.2 Problem statement

An aluminum metal is generated from either primary or secondary production from two types of methods. Primary production is a method from bauxite (ore) and secondary method is a method of recycling aluminum scrap. Based on Srinu, Giribabu and Sreedhar (2017), recycling methods can save production costs where nearly 95 percent of energy can be saved from recycling methods than from primary methods. A casting process method is engaged in the secondary process. The stated issue is the greater material loss during the casting process. 54 percent of waste aluminum becomes real products and 46 percent becomes scraps, and the most have been affected during a casting process.

Aluminum and its alloy are widely used in industry among the different types of materials. Aluminum alloys are light alloys that are used in metal structures, combining many advantages such as high stiffness, high specific strength, good dimensional stability, workability with good wear resistance and low density. The growing metal demand, and solid waste problem is one of the most popular issues that has received widespread public expansion despite the rising amount of aluminum used today coming from recycling as in automotive components (The Aluminum Association, 2011). Due to these factors, recycling becomes more competitive and the relative importance of secondary aluminum production to the community will grow. Aluminum recycling is one of the processes of aluminum scrap so that it can be reused in the product after its initial production. However, in the process of conventional aluminum recycling, losses such as damages made by metal oxidation during smelting, some damages assumed to mix with slag from the melting surface, and the remaining scraps are obtained from casting and further production of aluminum ingots. In the end, only 54 percent of the metal is reused (Capuzzi and Timelli, 2018).

Conventional recycling method generates harmful substances that generally involve removal at an elevated cost, even some vaporization methods are arising (Liu & Muller, 2012). Aluminum reduction can quickly exceed 50 percent and ultimately the cost of aluminum is very high, causing this traditional restoration process to be extremely inefficient (Duflou *et al*., 2015; Nakamura *et al*., 2012). Alternatives to aluminum regeneration are therefore required rather than conventional aluminum recycling as demand increases and to prevent the shortage of significant aluminum resources while reducing the cost of operating. At the same time, the recycling method can reduce air pollution.

Direct recycling method is a relatively new eco-friendly approach to minimize the processing cost issue. It is an intelligence method to prevent the casting process in secondary processes. This leads waste recycling to remain a significant issue. Recycled materials are much less expensive than conventional methods, which is why recycling is especially very common in developing countries. Cold compression with sintering process has been shown to have stronger characteristics than previous researches relative to other recycling methods (Chan Boon Loong, 2016). At the same time, conventional recycling performed with a melting phase requires pre-processing of the scraps to separate impurities. Losses occur at every stage of the recycling cycle owing to metal oxidation, scraps from casting and slag mixing (Capuzzi *et al*., 2018).

Consequently, this research presents a new approach to solid-state direct recycling of aluminum using cold compaction and sintering process techniques, which contributes to easier procedures and advantages from small energy consumption and operating costs (Chiba, Nakamura & Kuroda, 2011). The lowest energy consumption as criterion is implemented to optimize cold compaction technique. The enhance of mechanical properties by the reinforcement agents contributes to the sustainability of primary aluminum resources to recycled.

1.3 Objectives of the study

The main objectives of this study are:

(i) To produce rice husk silica reinforced AA7075 aluminum chip composites at 2.5, 5, 7.5, 10 and 12.5 wt% for enhanced physical and mechanical properties by using cold compaction method.

(ii) To investigate the effect of using amorphous and crystalline silica on the physical and mechanical properties of metal matrix composites.

1.4 Scope of the study

In this study, the AA7075 aluminum alloy is selected as the main material and converted to chips using a high-speed milling machine. Using an ultrasonic bath cleaner, the chip is cleaned using acetone solution and the chips are dried using dry oven.

Rice husk silica is selected as a reinforcing agent. Two types of rice husk silica is prepared as untreated and treated rice husk silica were treated rice husk silica using hydrochloric acid to fasten burning process. The grinding phase to reduce average particle size and increase specific surface area is performed using a high impact mill with a porcelain container. The sieving process then takes place to produce the silica particle size at 63 µm. X-ray fluorescence (XRF) test is conducted to characterize the content of silica in rice husk ash and X-ray diffraction (XRD) test is conducted to characterize the formation of crystalline phases of rice husk silica using 63 µm of particle size.

The recycled aluminum chip AA7075 is mixed with different composition percentages of rice husk silica (2.5, 5.0, 7.5, 10 and 12.5) wt% in 63 µm particle size with different crystalline phases of rice husk silica, and added with 1 % of zinc stearate as a binder to enhance the structural stability of material before being compacted using uniaxial compaction at 9 tons.

The mechanical properties of the sample undergo two types of testing. First is micro-hardness test which is the test conducted using Vickers Hardness machine to measure the hardness of sample, and the second is compression test where universal testing machine (UTM) is used to determine the behavior of materials under crushing

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